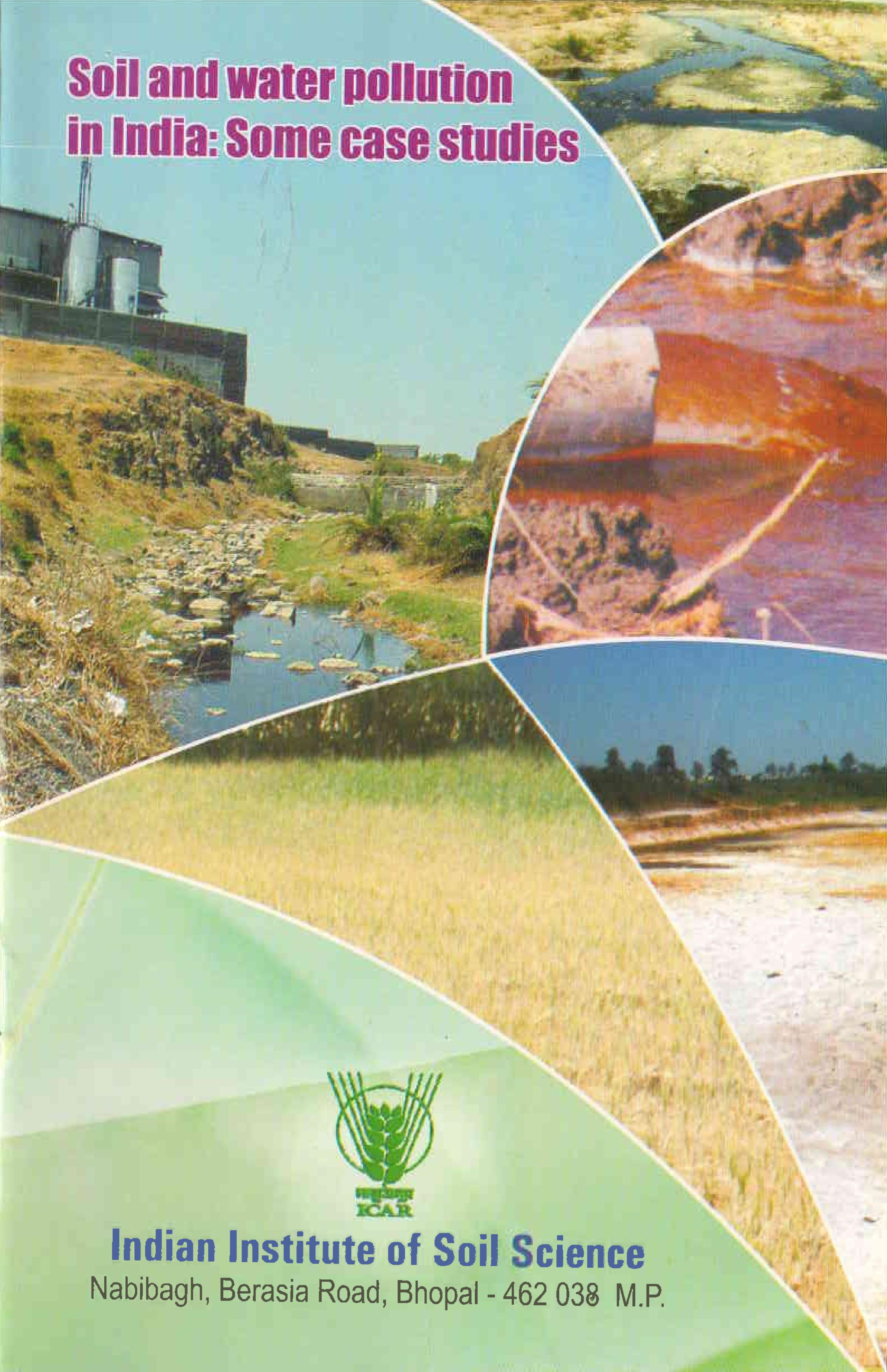
Soil and water pollution in India: Some case studies



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Forward

Environmental quality is one of the major issues and concerns worldwide. Of particular importance is the protection and sustainable use of valuable soil and water resources. In modern economies, various types of activity, including agriculture, industry and transportation, produce a large amount of wastes and new types of pollutants. With increasing human population, urbanization, concentrated animal production areas and expending industries, safe disposal of by-product materials is becoming a greater challenge. Often, these by-products are applied to land and their mismanagement is leading to soil contamination.

With continuous long term application of these waste by-products to land, accumulation of the pollutants is likely to exceed in Indian soils. There are some cities of India, where considerable pollution of surface and groundwater and also the agricultural soils using such polluted water as source of irrigation for crop cultivation has been reported. Indian Institute of Soil Science, Bhopal has carried out some investigative studies to understand the environmental impacts of industrial discharge of effluents/solid waste in surface and groundwater and soil pollution in and around cities. The study has generated useful information on the nature of contaminants and their effect on soil as well as given some clues for its amelioration/management of land and water resources in order to enhance their quality and crop productivity.

For commendable efforts made in generating information, I congratulate the project team associated with it. I hope that findings documented in this bulletin, will be useful to farmers, various extension agencies, policy makers as well as various investigating agencies in the related areas.

A. S

Bhopal
November, 2010

(A. Subba Rao)
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Preface

During the past few decades Indian industries have registered a quantum jump, which has not only contributed to high economic growth but simultaneously has also given rise to severe environmental pollution. Consequently, air, water and soil quality is seriously affected which is far lower in comparison to the international standards. The problem is worse in the case of soil and water pollution. It is found that one-third of the total pollution comes in the form of effluent discharge, solid wastes and other hazardous wastes. Untreated or supposedly treated effluents have increased the level of pollutants in critically polluted areas of the country. The surface water is the main source for waste disposal by industries. In India there are sufficient evidences available related with the mismanagement of industrial wastes. Consequently, at the end of each time period the pollution problem takes menacing concern. Most of the studies undertaken in the Indian context have been quite inconclusive. So far no clear-cut estimations have been made to determine the overall effects of the industrial pollution, especially industrial water and solid waste pollution. In very few instances the problem has been identified partially. In order to address the farming related issues, Indian Institute of Soil Science carried out some case studies under a research project "Developing database on soil and water pollution in India" during 2008 - 2010. Salient achievements of the project are presented in this bulletin. The findings of the present study can be useful for farmers, various extension agencies and policy makers.

Investigators of the project gratefully acknowledge the support and guidance of Dr. A. Subba Rao, Director, and all the Scientists of IISS, Bhopal for their valuable support, guidance and suggestions during the entire period of investigation. Our sincere thanks are also due to the staff of District offices of State Governments for providing valuable information related to the study and villagers of the affected area for their immense help in conducting the survey and providing relevant information. For successful completion of this project, authors express sincere gratitude to technical and supporting staffs of Division of Environmental Soil Science.

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Introduction

With the growing competition for water and declining freshwater resources, the utilization of marginal quality water for agriculture has posed a new challenge for environmental management. In water scarce areas there are competing demands from different sectors for the limited available water resources. Though the industrial use of water is very low when compared to agricultural use, the disposal of industrial effluents on land and/or on surface water bodies makes water resources unsuitable for other uses.

Domestic waste water has always been a low cost option for farmers to go in for irrigated agriculture in water scarce regions of the world. Apart from its resource value as water, the high nutrient content of domestic waste water helps the farmers to fertilize their crops without spending substantial amounts on additional fertilizers. In addition, temporal and spatial water scarcity, along with the rising demand for water from competing sectors (growing population, urbanization and industrialization), have also forced the farmers to go for waste water irrigation. However, safe utilization of waste water for irrigation requires the use of proper treatment and several precautionary measures in place, as it may cause environmental and human health hazards (Bradford et al. 2003; Minhas and Samra 2004; Butt et al. 2005). Currently, in India, most of the urban local bodies cannot afford to make large investments on infrastructure for collection, treatment and disposal of waste water, and as a result waste water is mostly used without proper treatment and adequate precautionary measures. In a developing country like India, industrial effluents as well as hospital and commercial waste often get mixed with domestic sewage, and unlike developed countries where industrial effluents often get mixed with domestic sewage to dilute industrial pollutants and toxicants for better/easier treatment. In India mostly urban diffused industrial units (mostly Small Scale Industries) dispose their untreated effluents in public sewers as a regular practice to avoid the costs of effluent treatment. In India only

24 per cent of waste water is treated (primary only) before it is used in agriculture and disposed into rivers, and that is also for Metrocities and Class – I cities (Minhas and Samra 2004). When treatment is not adequate, the application of domestic waste water on land might cause various environmental problems like groundwater contamination (bacteriological and chemical), soil degradation, and contamination of crops grown on polluted water (McCornick et al. 2004; Scott et al. 2004). Irrigation with treated/untreated industrial effluent is a relatively new practice, since it is seen (a) as a low cost option for waste water disposal, (b) as a reliable, assured and cheap source for irrigated agriculture, especially in water starved arid and semi-arid parts of tropical countries, (c) as a way of keeping surface water bodies less polluted, and also (d) as an important economic resource for agriculture due to its nutrient value.

Most of the units discharge their effluents on land ostensibly for irrigation within their premises. Over time, the effluents have percolated to the groundwater causing contamination. As a result, farmers in the adjoining areas have found the groundwater unsuitable for irrigation. In some cases, drinking water wells (deep bore wells) have also been affected. Continuous application of polluted groundwater for irrigation has also resulted in rising salinity in soil. To some extent farmers are coping with the problem by cultivating salt-tolerant crops and/or by using other sources such as river water for irrigation. Instances of industrial effluent disposal (mostly untreated or partially treated) on land for irrigation are very limited in developed countries like the USA, UK, Canada and Australia. In India having the option to dispose effluents on land encourages the industries to discharge their effluents either on their own land or on the surrounding farmlands in the hope that it will get assimilated in the environment through percolation, seepage and evaporation without causing any environmental hazards. Environmental problems related to industrial effluent disposal on land have been reported from various parts of India and other countries. Disposal on land has become a regular practice for some industries and creates local/regional environmental problems (Kannan and Oblisami 1990;

Narwal et al. 1992; Shivkumar and Biksham 1995; Kaushik et al. 1996; Lone and Rizwan 1997; Singh and Parwana 1998; NGRI 1998; Subba Rao et al. 1998; Tiwari and Mahapatra 1999; Pathak et al. 1999; Gowd and Kotaiah 2000; Subrahmanyam and Yadaiah 2001; Gurunadha Rao et al. 2001; Singh et al. 2001; Barman et al. 2001; Senthil Kumar and Narayanaswamy 2002; Salunke and Karande 2002; Behera and Reddy 2002; Kisku et al. 2003; Jain et al. 2005; Ghosh 2005; Müller et al. 2007). There is substantial literature on the benefits and costs of domestic sewage based irrigation practices (Qadir et al. 2000; IWMI 2003; Keraita and Drechsel 2004; Qadir et al. 2007). However, the disposal of industrial effluents on land for irrigation is a comparatively new area of research and hence throws new challenges for environmental and agricultural management (Subba Rao et al. 1998; Gurunadha Rao et al. 2001 Behera and Reddy 2002; Sundramoorthy and Lakshmanachary 2002; Bhamoriya 2004; Buechler and Mekala 2005; Singh and Bhati 2005; Garg and Kaushik 2006 and Narwal et al. 2006).

Water quality problems related to the disposal of industrial effluents on land and surface water bodies, are generally considered as a legal problem – a violation of environmental rules and regulations. However, Indian pollution abatement rules and regulations provide options to industries to dispose their effluents in different environmental media, e.g., on surface water bodies, on land for irrigation, in public sewers or marine disposal, according to their location, convenience and feasibility. There are different prescribed standards for different effluent disposal options (Table 1; CPCB 2001). As far as industries are concerned, their objective is to meet any one of those standards, which is feasible and convenient for them to discharge their effluents. The standards are set with the assumptions that the environmental media have the capacity to assimilate the pollution load so that no environmental problems will arise. However, when the assimilative capacity of the environmental media (surface water bodies or land) reach/cross the limits, large-scale pollution of surface water and groundwater occurs. Such instances have been recorded from industrial clusters in various parts of the country - Ambur; Thirupathur; Vellore; Ranipet; Thuthipeth; Valayambattu and Vaniyambadi of Vellore District, Kangeyam;

Dharapuram and Vellakoil of Erode District, Tiruppur at Coimbatore District and Karur at Karur District in Tamil Nadu (Thangarajan 1999; Sankar 2000; Appasamy and Nelliyat 2000; Nelliyat 2003, 2005); Vadodara, Bharuch, Ankleshwar, Vapi, Valsad, Surat, Navsari, Ankleswar in Gujarat (Hirway 2005); Thane – Belapur in Maharashtra (Shankar et al. 1994); Patancheru, Pashamylaram, Bollarum, Katedan, Kazipally, Visakhapatnam in Andhra Pradesh (Shivkumar and Biksham 1995; NGRI 1998; Subba Rao et al. 1998; Subrahmanyam and Yadaiah 2001; Gurunadha Rao et al. 2001 and Behera and Reddy 2002); Ludhiana, Amritsar, Jalandhar, Patiala, Toansa and Nangal - Ropar District in Punjab (Tiwari and Mahapatra 1999; Ghosh 2005). Since all the prescribed standards for disposal are effluent standards, the impact on ambient quality cannot be directly linked to disposal or vice versa, as a result point source in effect acts as non-point source pollution. In India and other developing countries pollution control of non-point sources is mostly neglected, point sources prefer to avoid pollution abatement costs through various pollution-sheltering activities like pumping untreated effluents to the groundwater and disposing hazardous wastes into open wells (Tiwari and Mahapatra 1999; Behera and Reddy 2002; Ghosh 2005 and Sharma 2005).

Table 1. Maximum permissible limits (mg/liter) for industrial effluent discharges.

Parameters	Into Inland Surface waters	On Land for Irrigation	Into Public Sewers	Marine Coastal area
Biological Oxygen Demand (for 5 days at 20°C)	30	100	350	100
Chemical Oxygen Demand	250	-	-	250
Suspended Solids	100	200	600	-
Total dissolved solids (inorganic)	2,100	2,100	2,100	-
Total residual chlorine	1	-	-	1
Cadmium (as Cd)	2	-	1	2
Hexavalent Chromium (as Cr^{+6})	0.1	-	2	1
Copper (as Cu)	3	-	3	3
Lead (as Pb)	0.1	-	1	1
Mercury (as Hg)	0.01	-	0.01	0.01
Nickel (as Ni)	3	-	2	5
Zinc (as Zn)	5	-	15	15
Chloride (as Cl)	1,000	600	1,000	-
Selenium (as Se)	0.05	-	0.05	0.05
Ammoniacal nitrogen (as N)	50	-	50	50

Source: CPCB 2001

In modern economies, various types of activity, including agriculture, industry and transportation, produce a large amount of wastes and new types of pollutants. Soil, air and water have traditionally been used as sites for the disposal of all these wastes. The industries require large volumes of water of high purity and in turn, they also generate equally large volumes of effluent with complex and highly variable chemical composition. During production process, huge quantity of water is used and most of the water goes to the environment after use, which pollutes the neighbourhood and influences the soil quality. Environmental pollution by metals became extensive as industrial activities increased in the late 19th and early 20th century.

The metal pollutants, ultimately derived from a growing number of diverse anthropogenic sources (industrial effluents and wastes, urban runoff, sewage treatment plants, agricultural pesticides runoff, domestic garbage dumps, and mining operations), have progressively affected the ecosystems more and more. All heavy metals are toxic at higher concentrations to plant, animal and human life. Almost all industries emanate some pollutants which are as follows:

Hazardous pollutants emanated from some industrial processes

Industry	**Major pollutant**
Battery	Pb, Cd
Brick and cement	Dust, fly ash, Si, F, organic pollutant
Drug and pharmaceutical	Halogen gases, minerals and organic compounds
Dye and dye stuff	Various organic pollutant
Electroplating	Mist of HCl, HF, N_xO_x, Chromic acid mist
Glass	Cr, Co, Cd, Ni, As, F, Si
Iron and steel works & foundries	Fe_xO_x, F, Mn, gases
Mining and metal	Pb, Cd, Ni, Be, Cu and oxides of N, S, C
Pesticides	Pb, As, Hg, Cr, organic pollutants
Printing	Pb, Cd, organic pollutants
Sugar mills	CO, SO_2, CO_2, HCl
Tanneries, textile	Cr, CO_2, tannic acid, NaOH, CS_2 etc.

soil and water/effluents sampling and 42 soil and 39 water/effluents samples were collected. The collected soil and effluents/water samples were processed and analyzed for heavy metals and other chemical parameters.

The result shows that the water of wells and tube wells in Cheerkhani and Silotia villages near to the industrial area is catogorised as high salinity EC (1.91 – 4.07 mS cm^{-1}) and sodium hazard (SAR > 10) and about 82 % of the samples have potential for severe Cl^- (>10 me L^{-1}) hazard permitting their use as irrigation in tolerant crops. The EC of some of the tube well waters of polluted villages has gone up more than 2.5 mS cm^{-1} indicating that effluents of industrial area have contaminated the ground water. The ground water samples of polluted area contained, on an average, 84.2 μg L^{-1} Cr, 3.7 μg L^{-1} Pb and 1.2 μg L^{-1} Cd. Surface soil samples of ground water polluted area

Industrial effluents in local nallah at Pithampur Industrial Area

Salt accumulation in soils at Cheerakhani and Silotia villages in Pithampur receiving polluted irrigation water

of Cheerkhani and Silotia villages had, on an average, higher EC (3.4 times), SAR (3.1 times). The soils of polluted villages (Cheerkhani and Silotia) showed considerable accumulation of Na, Cl^-. The soil receiving polluted ground water is also high in chromium (83-252 mg kg^{-1}) and manganese (710 – 1341 mg kg^{-1}).

The key findings:

1. The water of wells and tube wells in Cheerkhani and Silotia villages near to the industrial area is categorized as high salinity EC and sodium hazard.
2. 82 % of the samples have potential for severe Cl^- hazard permitting their use as irrigation in tolerant crops.
3. The soils of polluted villages showed considerable accumulation of Na, Cl^-.

2.2 Assessment of heavy metal pollution in groundwater as well as surface water in Patancheru Industrial area, Medak District, Andhra Pradesh, India

Patancheru industrial development area, covering about 120 km^2 has been established during mid-1970s on Hyderabad – Mumbai National highway (NH9) about 25km from Hyderabad city in Medak district, Andhra Pradesh, India. It is also identified as one of the most polluted area by Central Pollution Control Board, New Delhi, and referred to as an area of ecological disaster (CPCB, 2001). The study area forms part of Paddavagu stream, which comes under the catchment of Nakkavagu stream, a tributary of the Manjira River, which is one of the main sources of drinking water to Hyderabad city. It have about 300 pharmaceutical, heavy engineering, paints, chemical and paper factories established over the last two decades. They generate approximately 8 million liters of effluent water per day, most of which is directly discharged to the natural hydrological system, thereby causing imbalance to the environment (NEERI

1989). Before industrialization, the area had a high potential for fresh water recharge throughout the year and supported agriculture. The quality of groundwater in the area has deteriorated over the period and the level of pollution has increased continuously and consistently (Shivkumar and Biksham 1995). There has been no proper waste disposal facilities built in these areas, combined with this is the fact that industries have been want only disposing off their waste in nearby land or into water bodies. The combined industrial estates in Bollaram and Patancheru generate a cumulative 8 x 10^6 l/day of effluents which are directly discharged into surrounding land, irrigation fields and surface water bodies. The industrial effluents contain appreciable amounts of inorganic and organic chemicals and their by-products. Most of the industries are small to medium-scale sector and are not having any sewer lines. Many of them do not have proper waste water treatment plants and they discharge industrial effluents in unlined channels/streams, thereby causing contamination of air, water and soil.

The analytical results for both surface and groundwater are shown in Tables 2 and 3. The pH of surface water varies from 6.4 to 9.8 with an average of 7.9, while in groundwater it varies from 6.9 to 9.4 (average = 8.1). All the water samples show neutral to basic and alkaline values. pH does not show significant positive correlation with any trace element in surface and groundwater, while it shows negative correlation with As, Fe, Pb and Zn in surface water, and Mn and Sr in groundwater. This indicates that influence of pH on trace element is different in surface and groundwater of the study area, and is a major controlling factor especially in surface water. It was observed that there are some high values of Fe, Mn, As, Pb and Zn due to point and non-point sources, which may be attributed to the industrial and agricultural activities. The fact that surface water are either more acidic or alkaline in certain places, and that the trace elements concentrations in those samples are also varying accordingly, indicates that pH is a controlling factor in surface water. This situation suggests a strong variability due to presence of anthropogenic sources from surface water affecting groundwater.

Table 2. Anlaytical data of surface water ($\mu g\ l^{-1}$) collected from Pattancheru Industrial Area, Medak district

Parameters	Mean	Median	Minimum	Maximum
pH	7.9	7.8	4.4	9.8
EC (dS/m)	2.5	1.8	0.5	8.9
Cr	16.0	12.5	3.9	43.8
Mn	73.9	33.9	2.6	209.3
Fe	70.0	71.6	39.1	153.7
Ni	23.4	15.6	4.7	57.4
Zn	81.0	67.3	32.9	326.8
As	26.3	18.9	1.8	97.3
Pb	1.70	0.90	0.30	11.20
Sr	631	518	121	1672

Arsenic levels were found to be almost high in all samples with concentration ranging from 1.8 to 97.3 μg/l with an average of 26.3 μg/l. Peddavagu stream also show high concentration of arsenic (>1000 μg/l), which proves that source of arsenic is anthropogenic and not from any surrounding rocks. Organic effluents discharged by the industries can complex with arsenic to form non-degradable metal complexes and they in turn enter the groundwater and migrate along natural hydrological gradient. Arsenic contamination in Patancheru comes mainly from paint, pharmaceutical, fertilizer and pesticides industries.

Anthropogenic addition of Fe in surface water varying from 39.1 to 153.7 μg/l with an average of 70 μg/l is low in the area; apparently effluent waters are only causing its increase in surface water. Fe does not show high concentrations in groundwater suggesting that there is little percolation of Fe from surface to groundwater. Ni concentration varies from 4.7 to 57.4 (average of 23.4 μg/l), Pb varies from 0.3 to 14.2 μg/l (average of 2.0 μg/l) and Zn varies from 32.9 to 293.9 ppm (average of 81 μg/l). Some sample show high values of Fe, Ni, Pb and Zn, which are near the vicinity of industrial areas. The

Sr concentration varies from 121 to 1672 μg/l (average = 631 μg/l). Some samples show high values of Sr. High values of Sr up to 1000 μg/l can be derived from the surrounding acidic rocks having Sr of about 400–500 ppm. Hence Sr contamination is attributed to mixed origin of Sr in the area from anthropogenic and geogenic source.

The ground water contamination is higher in the study area (Table 3), which may be mainly due to anthropogenic activities or some geogenic also. Groundwater contamination can originate above or below the surface of the earth. Infiltration of polluted surface water causes contamination below the surface of the earth. When compared to water in streams and rivers, the movement of groundwater is very slow and hence once the contaminant reaches the groundwater; there is little scope for dilution and dispersion.

Table 3. Analytical data of Groundwater (μg l^{-1}) collected from Pattancheru Industrial Area, Medak district

Parameter	Mean	Median	Minimum	Maximum
pH	8.1	8.0	6.9	9.4
EC (dS/m)	2.6	1.7	0.7	10.2
Cr	13.3	6.9	2.0	69.7
Mn	75.8	5.6	2.4	11384
Fe	106.7	87.3	34.6	497.2
Ni	69.0	43.0	3.9	264.8
Zn	89.4	57.8	21.4	310.8
As	129.4	19.3	4.2	1139.0
Pb	2.10	0.95	0.30	7.20
Sr	1079	875	134	2681

The polluted surface water is strongly influencing the quality of groundwater in the study area. Migration patterns of heavy metals released into the environment in the form of untreated effluents by CETP and industries of Patancheru indicate the point source of pollution. The untreated effluents emerging from the industries must

Peddavagu stream (sewage canal) (a) Morning view (b) Evening view

Sewage canal just behind the CETP

Application of Paddavagu stream water for irrigation

be monitored for maintaining the standards prescribed by the pollution control board for various industries in the region. As the CETP receives effluents from various industries in tankers and it is suggested to check for the trace metal and TDS concentrations before letting the untreated effluents into the CETP.

The key findings:

1. All the water samples show neutral to basic and alkaline values.
2. There are some high values of Fe, Mn, As, Pb and Zn due to point and non-point sources, which may be attributed to the industrial and agricultural activities.
3. The ground water contamination is higher in the study area, which may be mainly due to anthropogenic activities or some geogenic also.

hazard (SAR > 9) and about 71% of the samples have potential for severe Cl hazard (>10 meq Cl L^{-1}) permitting their use as irrigation only in tolerant crops. Groundwater samples of polluted area contained, on an average, 9.1 µg L^{-1} Pb, 4.1 µg L^{-1} Cd and 18.5 µg L^{-1} Cu. Several samples from Bhajankheda, Jadwasa khurd and Dosigaon villages of polluted area contained unsafe levels of Pb and Cd for drinking purpose.

Nagda: A man made dam constructed at the upstream side of industrial area on the Chambal river withholds the fresh water during winter and premonsoon summer season for domestic and industrial use. During this period, downstream side of Chambal river carries mostly city and industrial effluents. Agricultural land of more than 14 villages at both side of the river are affected due to the use of effluent loaded river water for irrigation in winter season crops. Irrigation water (Chambal river) near affected villages had EC ranging from 2.38 to 4.11 mS/cm due to sulphate and chloride salts of Na (Table 4). The mean SAR value in Chambal river water was 5.1 times higher than that in unpolluted tubewell water. The EC of some of the tubewell water of polluted villages have gone up more than 2.5 mS/cm indicating that effluents of industrial area have contaminated the groundwater.

Table 4. Chemical properties of irrigation water in some affected and unaffected villages in Nagda

Parameter	Unpolluted area (Groundwater)		Polluted area (River water)	
	Range	Mean	Range	Mean
pH (1:2)	8.12-8.91	8.46	8.17-8.3	8.18
EC (dS m^{-1})	0.38-1.12	0.76	2.38-4.11	3.56
Na^+ (mM)	0.48-5.63	3.89	31.61-57.52	38.53
K^+ (mM)	0.10-0.21	0.12	0.44-1.16	0.92
Ca^{+2} (mM)	0.27-1.40	0.65	3.54-4.32	3.79
Mg^{+2} (mM)	0.29-1.90	0.78	1.07-2.72	1.43
SAR	0.51-6.87	3.24	14.64-21.69	16.70
Cl^- (mM)	2.46-6.62	3.72	25.63-25.77	25.73
SO_4^{-2} (mM)	0.34-0.49	0.39	2.93-6.76	3.50

Colored groundwater being used for irrigating the field in Jadwasa khurd village near Ratlam for sowing wheat crop

Polluted chambal river water being used as irrigation by farmers of Juna Nagda village

Changes in soil chemical properties due to continuous irrigation with polluted irrigation water Ratlam:

For this study, surface layer (0-15 cm) soil samples were collected from about 10 farmers' fields from each of the polluted villages; viz., Sejawata, Jadwasa khurd, Malwasa, Jadwasa kala, Kaloli, Simlawada, Bhatuni, Bhajankheda, Ghatala and Dosigaon. For comparision, surface soil samples were also collected from nearby villages (Karmdi, Titari, Kalmoda, Kuwazagari, Salakheri, Kharakheri) where groundwater is reported to be unpolluted.

Soil samples collected in the month of February from villages groundwater polluted area had, on an average, higher EC (4.5 times), SAR (4.6 times), organic C (1.5 times) and available K(22% more) as compared to the soils from unpolluted area. Soils of Jadwasa khurd, Jadwasa kala, Bhajankheda, Ghatala and Dosigaon villages were more degraded as indicated by high EC and SAR. Such a build up of salinity could result in considerable damage to several crops. Available (DTPA extractable) Zn and Cu contents in soils were sufficient.

Soil solution of affected villages, in general, had significantly higher concentrations of Na^+ (9.7 times), Ca^{+2}(1.9 times), Mg^{+2}(1.8 times), Cl^- (12.5 times), SO_4^{-2} (4.8 times) and HCO_3^- (2.3 times) than those of unaffected area. Concentration of K was similar but concentration of NO_3^- was more in soil solution of unpolluted area. Among the villages of affected area, Jadwasa khurd recorded maximum concentrations of Na^+, Cl^-, SO_4^{-2} and HCO_3^- in soil solution. Sodium, Ca, Mg and K constituted about 60, 28, 11and 1% of the major cations; while, Cl^-,SO_4^{-2}, HCO_3^- and NO_3^- constituted about 60, 10, 11 and 19% of the major anions in soil solution of affected villages. Similar values in unaffected villages were 38, 43, 16 and 3% for cations and 12, 18,

Total heavy metal contents in soils

Ratlam: Soils of polluted area contained, on an average, 83.5 ppm Zn, 57.9 ppm Cu, 1.72% Fe, 829.7 ppm Mn, 0.25 ppm Cd, 10.6 ppm Pb, 31.2 ppm Co, 108.0 ppm Cr and 56.8 ppm Ni. These contents were, on an average, 54.3% (for Zn), 71.8% (for Cu), 50.3% (for Fe), 66.1% (for Mn), 44.2% (for Cr) and 66.7% (for Co) less than their contents in soils of unpolluted area. However, contents of Pb and Cd were more in soils of polluted area. There was no difference in the content of Ni between the soils of polluted and unpolluted area.

Nagda: Soils of polluted area contained, on an average, 123.5 ppm Zn, 77.4 ppm Cu, 1.77% Fe, 844.5 ppm Mn, 0.2 ppm Cd, 7.6 ppm Pb, 31.9 ppm Co, 81.2 ppm Cr and 40.6 ppm Ni. These contents were, on an average, 23.7% (for Zn), 45.6% (for Cu), 25% (for Fe), 57.7% (for Mn), 51.7% (for Co), 60.6% (for Cr) and 57.5% (for Ni) less than their contents in soils of unpolluted area. There was no difference in the contents of Cd and Pb between the soils of polluted and unpolluted area. This indicates that heavy metal accumulation might not have taken place due to continuous use of polluted irrigation water in Ratlam and Nagda area.

The key findings:

1. Considerable contamination of groundwater with ions, particularly, Na^+, Ca^{+2}, Cl^- and SO_4^{-2} has been observed in groundwater near Ratlam industrial area.

2. Chambal river water has been severely polluted with industrial effluents at Nagda and contains high amount of salts, particularly, Cl^- and SO_4^{-2} salts of sodium with high SAR values.

3. Irrigation with these polluted water resulted development of salinity and sodicity in soils at both the places. In Ratlam, dominant salts ions were Na^+ and Cl^-; whereas, in Nagda, Na^+ and SO_4^{-2} were dominant ions in soil.

2.4 Soil and water pollution due to zinc smelter effluent in Udaipur, Rajsthan

The zinc smelter at Debari is about 14 kms east of Udaipur and was commissioned in January 1968 with a rated capacity of 18,000 TPA (tonnes per annum) of zinc ingots which later expanded to 45,000 TPA in 1976-77. With the expansion of smelter plant a number of other production units have been commissioned including sulphuric acid (87,000 TPA), cadmium metal (190 TPA), phosphoric acid (26,000 TPA), single superphosphate (72,000 TPA) and zinc dust (36,000 TPA). Since its inception the effluent from the plant has been discharged into a stream which flows about 3 kms to the east and merges into Berach river. For the major part of the year, only effluents discharged from zinc smelter flow in the river. Downward and lateral movement of the effluent through hydrologic cycle linked up with the underground water recharging wells situated in the area adjoining the effluent stream and river as well. As a consequence well waters of the area became polluted with the constituents of the effluent, mainly heavy metals which make the water unsuitable for drinking purposes. With the deterioration of the well water, the soil in the fields irrigated with the water was also contaminated. The present study attempts to evaluate the effect of the zinc smelter effluent on the degradation of soil and water resources.

The study area covering a distance of about 10 km from the effluent discharge point of the zinc smelter plant longitudinally and about 500 m laterally on both the sides of the stream and river carrying the effluent upto Mandesar. Samples of the effluent from the stream and river carrying it onward and water from thirty three wells located within the study area were collected during June 2009. Water samples were analyzed for electrolyte concentration (EC), pH, soluble cations and anions and for other toxicants using inductively coupled plasma optical emission spectrophotometer (ICP-OES). For the purpose of evaluation and interpretation these wells were categorized into nine groups based on their location laterally from the stream and longitudinally from the smelter's discharge point. The wells were categorized adjoining the effluent stream based on the lateral distance from the stream whereas those adjoining the river carrying the effluent based on their longitudinal distance from the discharge point.

Thirty three surface composite soil samples were drawn from the plough layer (15 cm depth) in June 2009, from the fields adjoining the stream and the river carrying effluent, starting from zinc smelter discharge point Gorla, Beechari, Gadva, Sihara, Oardi, Nandvel, Dabok, Toos Dangion to Mandesar villages. These samples were analyzed for their total and DTPA-extractable (available) metallic cations using ICP-OES and for other physico- chemical properties.

The effluent of zinc smelter containing different proportions of heavy metals is being discharged in a stream, employed for irrigating the crops in the vicinity of the smelter plant. The pH of the effluent being used for irrigation ranging from 5.8 to 7.8, was within permissible limit (5.5 – 9.0), however, the levels of zinc and fluoride were higher than permissible limit of 5 and 2 mg l^{-1}, respectively (BIS standard 1982). Its application for a number of years resulted in enrichment of toxicants in top soil and crop plants being thereon (Garg and Totawat, 2005).

Effluent from zinc smelter coming through sewage/effluent stream

Ground water quality:

The well waters were grouped into nine groups based on their location horizontally from stream/river and vertically from the Smelter's discharge point (Table 5) and the data on chemical composition of well waters and the effluent discharged from zinc smelter plant are presented in table 6. The EC of the well water adjoining to the stream as well as river (250 m vicinity) were high ranging from 3.0 to 5.0 dSm^{-1} and could be categorised into medium salinity water. However, the wells situated far off (>500 m laterally) have low EC (1.5 to 2.3 dSm-1) and were categorised into low salinity water. The effluent from the zinc smelter has direct effect on the quality of river water which in turn has polluted the groundwater in the wells situated in the vicinity of 200 - 300 meters. Further, the well waters in the nearby vicinity of the stream have become highly mineralized and unsuitable for drinking purposes. The pH of the well water examined followed the same trend as that of the effluent. However, it remained in safe limits.

The chloride content of the well water under study remained too high irrespective of the location of the well and quality of the effluent discharged, except in the case of wells categorized in group VII which followed the same trend as that of chloride concentration in the effluent. These wells are situated close to the river (22 to 90 m radius), giving enough opportunity to the chloride to diffuse. Like chloride, sulphate concentrations also remained too high but followed the same trend as that of their concentration in the effluent. Thus well waters adjoining the stream and river carrying effluent have

Table 5- Grouping of Wells by its Location

Group	Number of Wells	Distance from discharge point (m)	Lateral distance from stream and river (m)
I	2	100 to 1200	< 50
II	4	1200 to 1500	60 to 90
III	3	1500 to 2000	100 to 195
IV	5	2000 to 3000	200 to 250
V	4	3000 to 3700	40 to 220
VI	3	5000 to 5500	60 to 250
VII	5	6500 to 7500	22 to 90
VIII	4	8500 to 9000	40 to 100
IX	3	1500 to 3000	> 500

Table 6- Analysis of Well water collected from villages situated nearby HZL, Udaipur

Group No.	pH	EC	Na	K	Ca + Mg	CO_3^{-2}	HCO_3^-	Cl^-	SO_4^{-2}	Zn	Cu	Cd	Fe
		(dS/m)	(meq/L)							(µg/ml)			
I	8.05	6.27	23.7	0.3	35.5	2.2	3.4	10.8	44.1	9.70	0.009	0.081	0.343
II	8.22	6.42	24.9	0.2	38.4	1.2	3.6	9.0	48.9	7.78	0.010	0.028	0.355
III	8.12	5.37	27.6	0.2	26.2	2.8	3.6	16.6	29.8	4.75	0.007	0.015	0.345
IV	8.05	5.12	22.3	0.1	27.5	1.6	3.0	11.8	31.8	3.80	0.009	0.006	0.325
V	7.96	6.79	26.8	0.6	39.3	2.0	3.2	10.4	50.2	4.20	0.009	0.007	0.298
VI	8.05	6.43	28.7	0.5	33.7	2.2	2.8	8.6	47.9	6.33	0.006	0.005	0.283
VII	7.91	5.61	24.3	0.5	33.3	2.0	3.4	15.2	36.0	7.40	0.022	0.008	0.679
VIII	8.05	3.73	14.0	0.2	22.5	1.8	4.4	8.8	22.1	5.33	0.006	0.013	0.672
IX	7.89	3.14	12.4	0.1	17.8	2.0	4.0	7.1	18.2	2.16	0.005	0.004	0.253

been polluted with sulphate and chloride in a wide area to a considerable extent. The chemical equilibrium studies of polluted water have shown that these waters have reached saturation with calcium, sulphate and carbonate.

A change in the calcium and magnesium concentration of effluent has brought a change in their concentrations in well water sampled, although the level of calcium and magnesium remained lowest in the wells of group IX. The zinc content of the water from the wells of group I and VII falling within 50 to 90 m radius of the stream and river was initially high, even higher than its concentration in the effluent and limits permissible for irrigation water (2ppm). This may be attributed to the heavy build up of this constituent in the initial years in nearby vicinity when untreated acidic effluent was flowing as is also evident from its build up in the soil. The content of zinc changes with a change in its concentration in the effluent. Like zinc, cadmium content of the water from the wells grouped in I, II and VII which are located within 90 m radius of the stream and river, remained much higher than its limit of 0.005 ppm described for drinking and of 0.01 ppm for irrigation water.

Accumulation of heavy metals in the soil

A vast variation in the content of total zinc (65 to 1590 ppm), total cadmium (0.07 to 8.37ppm) and DTPA extractable zinc (19 to 173 ppm) have been recorded in the soils of area under study (table 7). The content of these ingredients in soils have a definite relationship with the location of the fields to the stream and the river carrying the effluent. With few exceptions, total zinc, cadmium and available zinc content of the soil decreases with an increase in the lateral distance from the stream and river. This indicates that pollution is mainly through irrigation from the wells which have been polluted by the underground flow of toxicants with water from the effluent stream as well as river. The distance from smelter and organic carbon content were important factors in determining the heavy metal distribution. A number of workers have reported that with increasing distance from the industrial zone, soil pollution by heavy metals and subsequently their levels in plant tissues were also decreased.

A significant positive correlation between total zinc and available zinc ($r = 0.71, P<0.01$) and total zinc and total cadmium ($r = 0.53, P<0.01$) indicate that they are interrelated and are possibly being contributed by the identical sources. Further, levels of total and available (DTPA - extractable) zinc recorded in the soil under study are mostly far above the levels reported for the most of mineral soils. The levels of total lead, copper, iron, cobalt and nickel varied in a very narrow range and unlike zinc and cadmium have no relationship with the location of

Table 7 - Chemical parameters of soil collected from study area

Parameter		Minimum	Maximum	Mean	Median
pH		7.2	10.4	8.2	8.3
EC (dS/m)		0.2	6.5	1.0	0.6
Zn	**DTPA**	19.0	235.0	77.4	69.0
Cu		0.7	3.2	1.3	1.3
Fe		1.7	6.4	3.2	3.1
Mn		2.3	14.9	9.1	9.3
Zn	Total	65	1860	619	590
Pb		27.5	180.0	51.4	38.0
Cu		21.2	70.0	36.0	34.9
Fe		14600	38600	24235	24100
Cd		0.07	10.37	1.56	0.86
Co		7.6	18.5	11.9	11.8
Ni		19.8	50.2	34.9	34.3

The view of soil irrigated with these contaminated water with effluents

the field to the effluent stream and river. Data on pH and ECe (electrical conductivity of the soil saturation extract) revealed that almost all soil samples examined were normal in regard to the production of agricultural crops except samples from Gadva, Bichhari and Mandesar, which were saline to saline-sodic in nature.

The key findings:

1. The concentration of heavy metals (Zn and Cd) is higher in well waters as well as in effluent irrigated soils nearer to the discharge point (Gorla and Bichhari village).
2. The concentration of these (Zn and Cd) heavy metals decreased with the distance from the effluent discharge point increases.

2.5 Soil and water pollution near Bandi river by textile industries in Pali, Rajsthan

Pali is one of the critically polluted areas identified by the Central Pollution Control Board in 1998. The industries here discharge a variety of chemicals, dyes, acids and alkalis besides heavy metals and other toxic compounds. Textile dyes are toxic, highly stable and do not degrade easily and are not removed by conventional waste water treatment methods. The textile printing and dyeing industries located in Pali town are discharging industrial effluents into the river Bandi, a non-perennial river with no flow in the lean season, thus severely contaminating both the river as well as the groundwater. There are more than eight hundred textile units in the city. Effluents from Pali flow about 55 km downstream, making the groundwater in several riverbank villages unfit for irrigation or drinking. According to a survey conducted by the Central Groundwater Board in 2004, the groundwater has turned alkaline and total dissolved solids, chloride, sulphate, sodium are very high in the groundwater rendering wells in the area unfit for drinking and even for irrigation. The soil in this area has also become hard and unfertile. In many sites heavy metals were also found (Anonymous 2004).

According to the Rajasthan State Pollution Control Board (RSPCB) these units discharge approximately 34 million litres per day (mld) today (Singh and Singh, 2005). Since 1983, three common effluent treatment plants (CETPs) with a capacity to treat 22.5 mld of industrial effluent have been installed. There are two units located at the Mandia road industrial area (CETP I and CETP II). These two CETPs receive waste water from the Mandia road industrial area and the 130 units located at industrial area Phase I, Phase II, Mahaveer Udyog Nagar and Maharaja Shree Umaid mill and are connected to CETP III at Punayata Road. Considering that textile industrial effluents are known to have toxic organic chemicals and metals like chromium, mercury and copper, they need to be properly treated at the CETP. Whereas, the CETPs in Pali have not been designed to monitor or treat heavy metals before they are let into the river.

Therefore a study to monitor the effect of treated and/or untreated effluents coming from textile industries in up- and down-stream of Bandi River on soil and water.

Soil, effluent, sewage and groundwater samples were collected from various villages (10) where industrial sewage water is used for irrigation i.e., Mandia, Javadia, Kerla, Gadhwara, Phekaria, Sukarlai and Nehada in down stream of Bandi river and Hemavas, Iycea and Sonai Maji in upstream of Bandi river, Pali. These sewage/effluents from Pali industrial area is directly coming to Bandi river which is a tributary of Luni river. The soil, effluent/sewage and water samples were analyzed for their physico-chemical characteristics and for other toxicants using inductively coupled plasma optical emission spectrophotometer (ICP-OES).

Ground water quality:

The well waters collected from these villages were grouped in upstream and down stream. The results clearly indicates that ground water from downstream villages (Javadia, Kerla and Sukarlai) were highly saline as compared to upstream villages (Icyea and Hemavas). These well waters were high in soluble Na which clearly affects the soil properties (Table 8).

Table 8. Chemical characteristics of groundwater in selected villages near Pali

Position	Village	pH	EC (dS/m)	Na^+	$Ca^{+2} + Mg^{+2}$	Cl^-	$CO_3^= + HCO_3^-$
				(meq/L)			
DOWNSTREAM	Jewadiya	8.69	9.54*	82.7	13.4	89.2	4.6
	Kerla	8.42	7.49$^{\#}$	74.2	8.2	74.8	6.2
	Sukarlai	8.27	6.81$^{\$}$	54.9	11.6	63.2	6.2
	Nehada	8.56	7.68	73.8	13.6	68.4	4.0
	Phikaria	8.51	6.74	42.9	18.4	54.7	3.2
	Gadhwara	8.39	5.91	51.3	7.4	51.6	5.0
UPSTREAM	Iycea	7.74	3.82	24.9	11.8	34.2	2.8
	Hemavas	7.93	4.16	28.3	13.2	36.0	3.4

*21.57 (Max.) # 14.17 (Max.) $ 16.32 (Max.)

Polluted Bandi river with textile mill effluents

Table 9 - Heavy metal (µg/ml) pollution in groundwater in selected villages around Pali

Position	Village	Cu	Zn	Pb	Ni	Cr	As
DOWNSTREAM	Jewadiya	0.17	0.07	0.02	0.14	0.04	0.28
	Kerla	0.52	0.12	0.39	1.07	0.11	0.49
	Sukarlai	0.05	9.31	0.07	0.42	0.27	0.03
	Nehada	0.07	0.06	0.08	0.09	0.05	0.02
	Phikaria	0.13	0.03	0.03	0.26	0.06	0.13
	Gadhwara	0.16	0.09	0.04	0.21	0.06	0.07
UPST REAM	Iycea	0.03	0.04	0.03	0.04	0.03	0.01
	Hemavas	0.02	0.03	0.01	0.03	0.01	ND
Drinking water standard		0.05	5.00	0.05	-	0.05	0.1

The heavy metal content of well water samples clearly show that Cu is above the drinking water standards in all the wells in downstream villages; Pb is high in Kerla, Sukarlai and Nehada; Cr level is high in Kerla, Sukarlai, Gadhwara and Phikaria; As is high in Jewadiya, Kerla and Phikaria (Table 9). Nickel, for which there is no standard, was detected in all villages. The above well water is coming well within permissible limits with regard to heavy metals but due to high salinity it is not suitable for irrigation. The soils cultivated by using contaminated well waters were also show high salinity (irrigation with high saline water). These soils were not high in any of the heavy metal (Table 10).

Table 10- Chemical characteristics and total heavy metals (ppm) in soil irrigated with contaminated well waters nearby Bandi river

Parameter	Downstream villages			Upstream villages		
	Range	Mean	Median	Range	Mean	Median
pH	7.84 – 8.93	8.37	8.59	7.57 - 8.34	7.92	7.83
EC (dS/m)	4.79 – 11.43	7.38	7.74	2.06 - 4.37	2.75	2.83
O.C. (%)	0.09 – 0.21	0.13	0.13	0.11 - 0.19	0.14	0.13
Co	3.25 - 12.7	7.64	7.025	6.60 - 12.7	9.27	8.50
Cd	N.D.- 0.20	0.10	0.10	N.D. - 0.10	0.02	N.D.
Pb	0.15 - 6.50	3.98	4.75	0.15 - 2.50	1.35	1.40
Cr	23.5 - 57.2	37.67	35.45	13.5 - 26.9	21.20	23.20
Ni	9.3 - 32.1	17.74	20.25	12.9 - 19.8	17.3	19.15

The river water was also collected from three different locations and analyzed for their pollution status (Table 11 – 12). The results clearly show that river water shows high salinity at Mandia bridge and at Nahada dam. The soluble Na content was higher at Mandia bridge. It is clearly indicated from table 11, river water samples show presence of heavy metals even at Nehada dam (50 km from Pali town).

Table 11 - Chemical properties of polluted of Bandi river

Location	pH	EC	Na^+	$Ca^{+2} + Mg^{+2}$	Cl^-	$CO_3^= + HCO_3^-$
		(dS/m)	(meq/L)			
River Bandi before Pali	7.64	3.1	6.9	21.2	27.8	1.8
River Bandi at Mandia Road Bridge	8.61	17.9	149.6	26.0	162.6	3.0
River Bandi at Nehada dam (50 km downstream)	8.49	12.2	92.7	28.4	108.0	2.8

Soil irrigated with contaminated well waters become saline

Table 12 - Heavy metal (µg/ml) pollution status of the Bandi river

Location	Cu	Zn	Pb	Ni	Cr	Cd	As
River Bandi before Pali	0.05	0.03	ND	ND	ND	ND	ND
River Bandi at Mandia Road Bridge	0.46	0.19	0.05	0.09	0.19	ND	0.05
River Bandi at Nehada dam (50 km downstream)	0.19	0.13	0.04	0.17	0.12	ND	0.06

ND : Not detectable

The key findings:

1. The currently installed CETPs are not designed to treat all the waste generated. Moreover, there is no guarantee that he waste is diverted for treatment as the inlet is designed for bypass also.
2. The technology used at CETPs was very old as the textile industries now shifted to new technology (synthetic). Therefore, heavy metals treatment is not available in these CETPs.
3. The Nahada dam built for storing water, become a industrial storage tank and thus leads to groundwater contamination.

2.6 Impact of the use of polluted irrigation water/effluent on soil quality near Korba (Chhattisgarh) industrial area

Korba city in Chattisgarh, is the Power Capital of Central India with the NTPC's Super Thermal Power Plant in Korba is working at 90% Plant Load Factor. There are huge coal reserves in the vicinity, offering cheap pithead power generation opportunities and there is enough water from the State's largest reservoir of Hasdeo Bango. 84% of India's coal is in Chhattisgarh and two other States. Korba is also the site of an aluminium facility operated by Bharat Aluminium Company (BALCO). There are number of ancillary industries also working in Korba. An ancillary unit is defined as a unit which produces parts, components, sub-assemblies, and tooling for supply against known or anticipated demand of one or more large units manufacturing/assembling complete product and which is not a subsidiary to or controlled by any large unit in regard to the negotiation of contracts for supply of its goods to any large unit.

The other industries which also situated in Korba are Ready Made Garments, Textiles, Engineering Workshops, Tyre Retreading, Fabrication, Hardware (Aluminum & Iron), Detergents, Plastic Toys, P.V.C Cable Pipes, Cement Products, Electricity Transformer, Truck Body Building, Bakelite, Distemper, Clay Insulator, Paper Pins, Calcium Chloride, Color Meethiline, Ferrovanadium, Pipes and Bricks etc. manufacturing units.

The ancillary industries near Kharmora and Rajgamar road generate large quantity of acidic effluent, which directly drained in agricultural fields and contaminate the soil. Therefore a study was taken to evaluate the effect of these effluents on soil quality.

Soil and water samples were collected from Kharmora village in June 2008 and April 2010. These samples were analyzed for their total and DTPA-extractable (available) metallic cations using ICP-OES and for other physico- chemical properties.

The data on water samples (normal and contaminated) collected from normal as well as polluted sites clearly indicates the presence of heavy metals, which is not suitable for drinking as well as irrigation purpose (Table 13).

Table 13. Heavy metals content in water samples collected from Kharmora village

Heavy metal	Normal water			Polluted water		
	Range	Mean	Median	Range	Mean	Median
Cd	0.000-0.002	0.001	0.001	0.000-0.056	0.000	0.009
Co	0.003-0.004	0.003	0.003	0.019-0.399	0.201	0.197
Cr	0.007-0.031	0.019	0.019	0.082-0.126	0.112	0.107
Cu	0.004-0.027	0.016	0.016	0.006-0.055	0.025	0.027
Fe	0.323-0.652	0.488	0.488	0.181-91.35	3.184	22.392
Mn	0.00-0.042	0.026	0.026	0.881-22.09	6.918	8.194
Ni	0.001-0.016	0.008	0.008	0.007-0.162	0.043	0.069
Pb	0.000-0.003	0.001	0.001	0.004-0.015	0.005	0.007
Zn	0.003-0.010	0.006	0.006	0.008-0.344	0.060	0.108
Na	26-318	72	46	19-2307	457	1031

The results clearly indicated that the soil irrigated with effluent is highly acidic in nature (Table 14). The total as well as DTPA extractable heavy metals were also in toxic range, particularly, Cr and Cu. Waste water irrigation is known to contribute significantly to the heavy-metal content of soils. A number of previous studies from developing countries have reported heavy-metal contamination in waste water and waste water-irrigated soil. The except pH, other soil properties viz. EC, soil organic carbon, DTPA extractable heavy metals and total heavy metals were increased with the application of industrial waste/effluent or contaminated water as compared to the non-polluted soils.

Table 14. Soil physico-chemical properties and heavy metal status of Kharmora village in 2008 and 2010

Parameter	2010		2008	
	Mean	STDEV	Mean	STDEV
pH	4.61	±0.093	5.07	±0.069
EC (dS/m)	2.21	±0.196	2.18	±0.127
O.C. (%)	0.46	±0.062	0.49	±0.043
DTPA extractable heavy metals (ppm)				
Cd	0.182	±0.019	0.149	±0.006
Co	1.726	±0.029	1.640	±0.032
Cr	0.096	±0.006	0.094	±0.008
Cu	2.356	±0.038	2.150	±0.040
Ni	1.828	±0.028	1.686	±0.042
Pb	5.944	±0.042	2.098	±0.052
Zn	1.350	±0.062	1.180	±0.044
Total heavy metals (ppm)				
Cd	8.10	±0.031	5.89	±0.028
Co	25.1	±0.42	23.9	±0.59
Cr	172.3	±6.41	132.5	±5.17
Cu	40.5	±3.86	36.0	±4.19
Ni	14.1	±0.86	12.6	±1.26
Pb	15.3	±2.16	11.8	±1.57
Zn	29.4	±2.31	25.8	±2.69

View of polluted site due to direct application of waste water in Kharmora village

View of polluted soil in Kharmora village

The key findings:

1. Water samples collected from polluted sites clearly indicates the presence of heavy metals, which is not suitable for drinking as well as irrigation purpose.
2. Soil irrigated with effluent is highly acidic in nature.
3. The total as well as DTPA extractable heavy metals were also in toxic range, particularly, Cr and Cu.
4. Waste water irrigation is known to contribute significantly to the heavy-metal content of soils.

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